BEAM OPTIC MEASUREMENTS FOR THE BOOSTER SYNCHROTRON OF THE DIAMOND LIGHT SOURCE

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Abstract

The booster synchrotron of the Diamond Light Source is a full energy injector ramping from 100 MeV to 3 GeV with a repetition rate of 5 Hz. As part of the booster commissioning, beam optic measurements were performed to characterise the booster performance. Through the use of the beam position monitors, orbit corrections and tune measurements were performed at injection energy and during the ramp. A first comparison with the booster model is also discussed.

INTRODUCTION

The Diamond booster synchrotron[1] is a missing-dipole FODO lattice structure with a circumference of 158.4 m. The electron beam coming from a 100 MeV Linac is injected on-axis into the booster at 5 Hz, ramped to 3 GeV and then extracted using a kicker magnet, pre-septum and main septum magnets. This beam is then transported for injection into the storage ring. The booster will operate in single and multi-bunch modes with a nominal emittance of 142 nm suitable for operation in top-up mode.

The booster commissioning began in December 2005 with DC operation at 100 MeV. Due to some delays with the water cooling system, the initial part of the commissioning was carried out at a reduced energy of 700 MeV, and 3 GeV operations has only been possible from May 2006 with first extraction at 3GeV achieved at the beginning of June[2]. We report here the results of the beam optics measurements and the characterisation of the booster performance at 700 MeV and the initial results of 3 GeV commissioning.

BOOSTER LATTICE

The booster lattice comprises 36 dipoles, two families of 22 quadrupoles, two families of 16 sextupoles and 22 correctors in each plane of motion. All these magnets can be ramped. DC operation is also possible although at a reduced dipole current and was used only at injection energy.

The optical functions of the booster lattice for the nominal working point ($\nu_x = 7.16$, $\nu_y = 4.11$) are shown in Fig. 1 and the main parameters are listed in Tab. 1. The nominal working point was chosen to provide a good dynamic aperture and a small natural emittance for efficient injection in the storage ring [3, 4]. Theoretical investigations of the lattice revealed that the emittance is below 150 nm in a broad range of tune space (ν_x = 6.8 to 7.4 and ν_y = 3.8 to 4.9), with several solutions providing good dynamic aperture. As such, a number of alternative working points were available for booster operation, and the ultimate selection has been made based on the best transfer efficiency and is slightly different to the nominal design one.

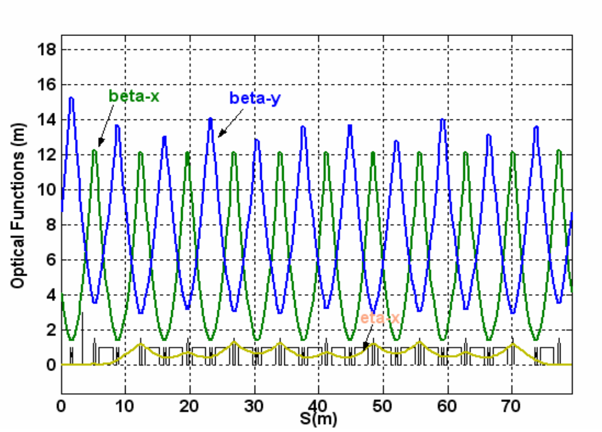

Figure 1: Optic functions and dispersion for the design working point of the booster.

Table 1: Main parameters of booster at 3GeV

Extraction energy	3 GeV
Injection energy	0.1 GeV
Circumference	158.4 m
Super period	2
Repetition rate	5 Hz
Harmonic number	264
Emittance	142 nm.rad
Momentum compaction	0.025
Energy spread	0.073 %
Energy loss/turn (@ 3 GeV)	576 KeV
Cavity voltage (@ 3 GeV)	1.1 MV
Natural chromaticities (ξ_x, ξ_y)	-1.26, -1.45
Damping times (τ_x, τ_y, τ_z)	5.8, 5.5, 2.7 ms
Nominal working point (ν_x, ν_y)	7.16, 4.11

CLOSED ORBIT MEASUREMENTS

The BPM system was available from day one of commissioning and allowed a simultaneous measurement of first turn, turn-by-turn and closed orbit at any point during the ramp. Orbit measurements taken during DC operation show a maximum orbit distortions of $\Delta x = \pm 6$mm and $\Delta y = \pm 4$mm. Closed orbit corrections using the model response matrix and an SVD algorithm reduced the r.m.s. orbit distortion to less than 1 mm in both planes. An example of orbit correction at injection energy, during the 3 GeV commissioning, is shown in Fig. 2.

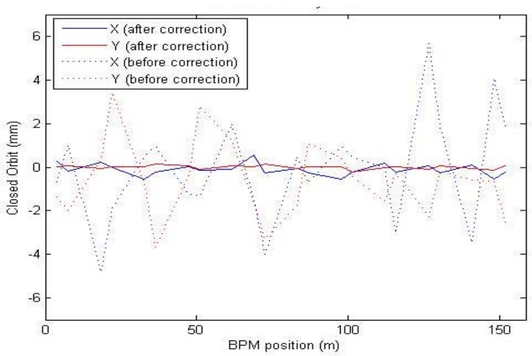

Figure 2: Closed Orbits at inject on energy during 3 GeV commissioning before and after correction.

Orbit measurements during the ramp were also routinely taken during commissioning to both 700 MeV and 3 GeV. An example plot taken when ramping to 3GeV is shown in Fig. 3 where the orbit was corrected only at injection energy without ramping the correctors. The orbit measured during the ramp increases rapidly until the beam energy reaches 400 MeV, then it remain constant at less than 3 mm peak value in both planes. Orbit corrections during the ramp have also been demonstrated, but they are not required as the acceleration and extraction efficiency are not further improved.

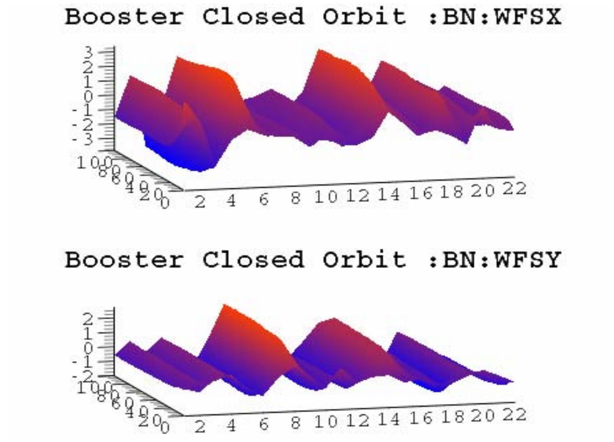

Figure 3: Closed orbit during ramp to 3 GeV with orbit correction at injection energy.

MEASUREMENT OF THE BOOSTER OPTIC FUNCTIONS

Betatron tunes and response matrix measurements allowed the characterization of the optics and the optimization of the injection process during both DC and in ramped mode at 700 MeV and 3 GeV.

The integer part of the betatron tunes was inferred from orbit response matrix measurements. In Fig. 4 we report a single column of the response matrix and the corresponding column computed from the model. The comparison clearly confirms the integer tune values of 7 and 4 in horizontal and vertical respectively.

Fractional betatron tunes are identified by exciting the beam with striplines and taking the FFTs of the BPM turn-by-turn data[5]. Tune drifts during the ramp to 700MeV were corrected by modifying the quadrupole waveforms in the digital booster power supplies. Following correction, horizontal and vertical tunes are restricted to the range $\Delta\nu_x = 0.1$ and $\Delta\nu_y = 0.05$. A better tracking of dipole and quadrupole ramps to 3 GeV has reduced the tune drifts to the range $\Delta\nu_x = 0.07$ and $\Delta\nu_y = 0.05$, using perfect sinusoidal waveforms. Plots of the fractional tunes during the 3 GeV ramp are shown in Fig. 5.

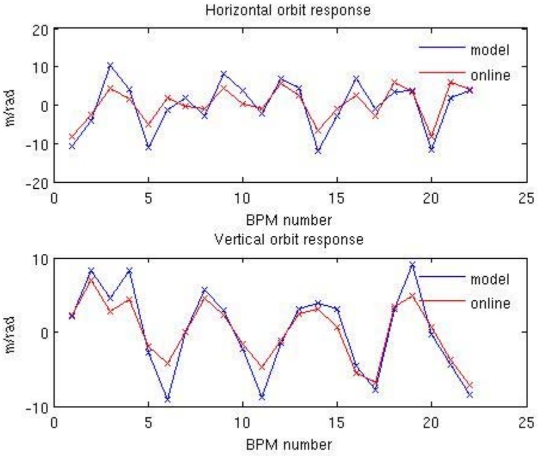

Figure 4: Comparison between measured and theoretical orbit response taken during DC operation.

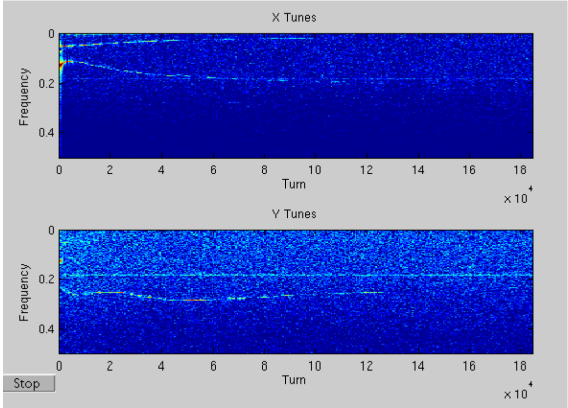

Figure 5: Tune variations during ramp to 3GeV.

The dispersion was measured during the 700 MeV commissioning by varying the master oscillator frequency by ± 30 kHz. A comparison with the model dispersion function is reported in Fig. 6.

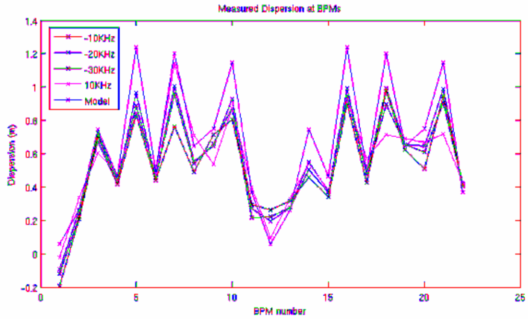

Figure 6: Dispersion measured by changing frequency by 10, 20 and 30 kHz compared to the theoretical values.

The spread in the measured dispersion values is thought to be due to shot-to-shot variations in the closed orbit measurements.

The chromaticities have been reduced at injection by minimising the amplitude of the synchrotron side bands of the tune signal (see Fig. 7). The two families of sextupoles can also be used to correct the chromaticities during the ramp, including that due to dipole-induced eddy currents in the stainless steel vacuum vessel walls, however it has not been attempted yet..

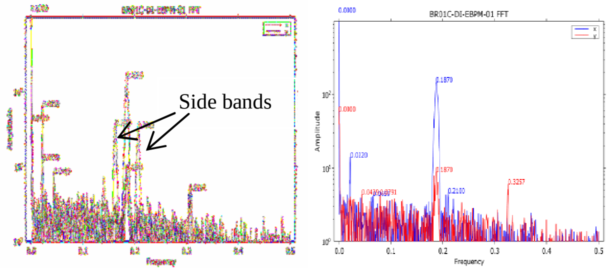

Figure 7: Comparison of tune signal before (left) and after (right) chromaticity correction (700MeV trials).

LOCO AND MODEL COMPARISONS

In order to measure the beta functions and the symmetry of the lattice, the LOCO algorithm[6] has been applied to the machine during commissioning at 700 MeV. LOCO compares the measured and the theoretical response matrices in order to calibrate the machine model. The results of the application of LOCO are shown in Figs. 8: Fig. 8a shows the measured response matrix, Fig. 8b the fitted gradients of the 22 focussing quadrupoles and Fig. 8c shows the reconstructed beta functions.

The gradients of the QD quadrupole family fitted with LOCO have an r.m.s. distribution of 1%, which is consistent with the measured field data. The gradients of two quadrupoles of the QF family differ by more than 3% but these errors gradually disappear as the beam energy increases and their origin is not fully understood. A β-beating of up to 15% is predicted by LOCO when compared with the ideal lattice (see Fig.8c).

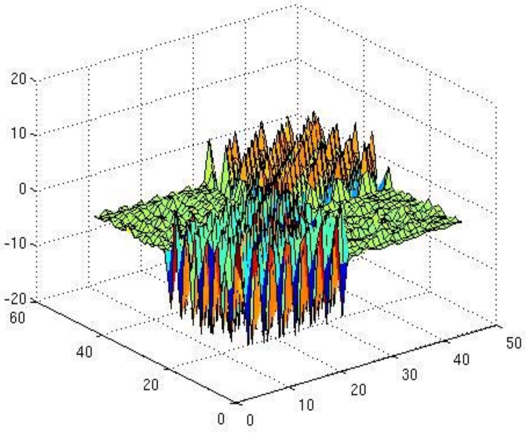

Figure 8a: Measured Response Matrix.

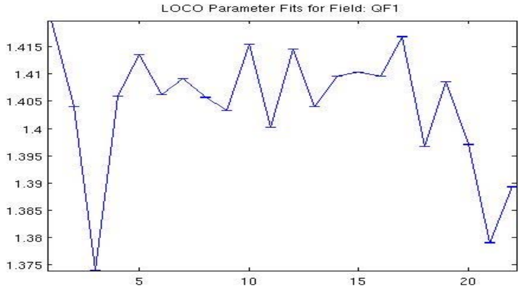

Figure 8b: LOCO reconstructed quadrupole gradients.

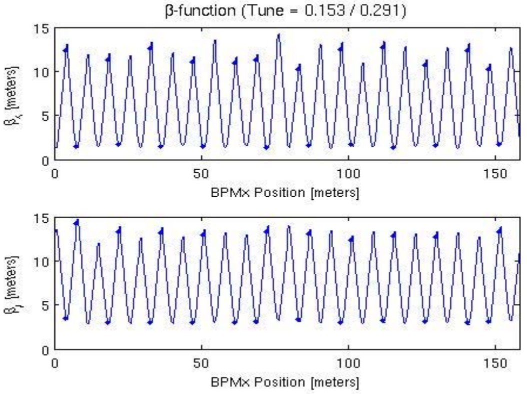

Figure 8c:LOCO reconstructed β-functions for the working point (ν_x=7.15, ν_y=4.29).

CONCLUSIONS

During the commissioning of the Diamond booster, various optical measurements have been made to characterize the lattice optics. The booster has been found to operate well, close to the design working points during 700 MeV commissioning and the initial tests at 3 GeV confirm these results. Closed orbit correction can be performed at injection and during the ramp using just the theoretical model. Orbit correction during the ramp, although possible, is not required. The tunes drift during the ramp have been corrected using modified ramps for the quadrupoles at 700 MeV. Tests with LOCO at 700 MeV showed that the lattice symmetry is good and β-beating is of the order of 15%.

Finally, the authors would like to thank all the members of the Diamond commissioning team for their collaboration during the measurements and help with the related software. The assistance of G. Portmann in the LOCO tests for the booster commissioning is gratefully acknowledged.

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